CLAIMS

1. A method of measuring at least one selected parameter at a location within a region of interest, which method comprises the steps of:

launching optical pulses at a plurality of preselected interrogation wavelengths into an optical fiber deployed along the region of interest, reflectors being arrayed along the optical fiber to form an array of sensor elements, the optical path length between the said reflectors being dependent upon the selected parameter;

detecting the returned optical interference signal for each of the preselected wavelengths; and

determining from the optical interference signal the absolute optical path length between two reflectors at the said location, and from the optical path length so determined the value of the selected parameter at the said location.

2. A method as claimed in claim 1, wherein the step of determining the absolute optical path length comprises carrying out a process in which the derivative of the phase as a function of wavelength is estimated from a subset of the interference signals, using the derivative and an estimated value for the optical path length to estimate the phase relationship between the interference signals, and the phase relationship thus obtained is used to revise the estimated value for the optical path length, the process being repeated for increasing subsets of the remaining wavelengths in sequence, on the basis of the optical path length estimated for the immediately preceding subset in the sequence, thereby

to progressively revise the optical path length until it is known to a desired level of accuracy.

3. A method as claimed in claim 2, wherein at least one of the subsets comprises a pair of the interference signals.

4. A method as claimed in any preceding claim, wherein said optical fiber comprises polarization-maintaining fiber and light is launched into the fiber in such a way that the power of the light signal is substantially equally divided between the orthogonally-polarised propagation modes of the fiber, thereby to interrogate each principal state of polarization of the fiber simultaneously, the return interference signals from both principal states of polarization being used separately in the said process for determining the absolute optical path length for each propagation mode independent of the other mode.

5. A method as claimed in any one of claims 1 to 3, wherein the optical fiber comprises polarization-maintaining fiber and light is launched into the fiber in such a way that the power of the light signal is firstly directed entirely into one of the principal states of polarization and then the other, thereby to interrogate the principal states of polarization sequentially, the returned interference signals from both principal states of polarization being used separately in the said process for determining the absolute optical path length for each propagation mode independent of the other mode.

6. A method as claimed in any one of claims 1 to 5, in which the selected parameter comprises temperature.

7. A method as claimed in claim 6, wherein the region of interest lies within a pipeline, and the method further comprises identifying any temperature variation within the pipeline from the determined value of the temperature at the said location, where temperature variations are indicative of a change of flow of a fluid in the pipeline.

8. A method as claimed in claim 7, wherein the change of flow arises from a leak of fluid into or out of the pipeline, and the method comprises identifying a leak at the said location from the identification of a temperature variation at that location.

9. A method as claimed in claim 7, wherein the change of flow arises from a constriction in the pipeline, and the method comprises identifying a constriction at the said location from the identification of a temperature variation at that location.

10. A method as claimed in any one of claims 1 to 5, in which the selected parameter comprises strain.

11. A method as claimed in claim 10, wherein the optical fiber is a high-birefringence fiber, the birefringence of which changes in response to strain applied to the optical fiber.

12. A method as claimed in claim 11, wherein the birefringence of the high-birefringence fiber also changes in response to temperature, and the method further comprises

compensating the returned optical interference signal for effects arising from temperature at the said location.

13. A method as claimed in any one of claims 10 to 12, wherein the region of interest lies on the surface of a component in an oil well, and the method further comprises identifying movement of the component from the determined value of strain.

14. A method as claimed in any one of claims 1 to 5, in which the selected parameter comprises pressure.

15 A method as claimed in claim 14, wherein the said optical fiber comprises a side-hole fiber.

16. A method as claimed in claim 15, wherein each sensor element of the fiber is located within a sealed elliptical tube filled with a pressure-transmitting fluid.

17. A method as claimed in claim 16, wherein the region of interest lies within a pipeline and the method comprises deploying two or more such optical fibers at different azimuths around an inner surface of the pipeline, and determining a density of fluid in the pipeline from the values of pressure determined for each optical fiber.

18. A method as claimed in claim 16, wherein the region of interest lies within a pipeline and the method comprises deploying two or more such optical fibers at difference azimuths around an inner surface of the pipeline, and determining an orientation of the pipeline and/or the optical

fibers from the values of pressure determined for each optical fiber.

19. A method as claimed in any one of claims 1 to 5, wherein the selected parameter depends on a localized event moving along the region of interest, and the method comprises determining the value of the selected parameter over time at more than one said location, and determining the movement of the localized event from the determined values of the selected parameter.

20. A method as claimed in claim 19, wherein the localized event is a user-induced event, and the method further comprises inducing the localized event.

21. A method as claimed in claim 19 or claim 20, wherein the localized event is a volume of fluid within the region of interest that has a different temperature, pressure, or density from surrounding fluid in the region of interest, the selected parameter being temperature, pressure, or density, respectively.

22. A method as claimed in any preceding claim, wherein at least two selected parameters are measured simultaneously.

23. A method as claimed in any preceding claim, further comprising the steps of launching optical pulses at a plurality of wavelengths into an additional optical fiber deployed along the region of interest, reflectors being arrayed along the additional optical fiber to form an additional array of sensor elements, the optical path length

between the said reflectors being dependent upon a further selected parameter; detecting the returned optical interference signal from the additional optical fiber for each of the preselected wavelengths; and determining from the optical interference signal the absolute optical path length between two reflectors at the said location, and from the optical path length so determined the value of the further selected parameter at the said location.

24 A method as claimed in claim 23, wherein the said optical fiber and the said additional optical fiber share the same fiber jacket.

25. A method as claimed in claim 23, wherein the said optical fiber and the said additional optical fiber are constituted by a single fiber sensitive to both parameters, the fiber having two cores.

26. A method as claimed in any preceding claim, wherein the measured value for the parameter is used to determine the value for a further measurand dependent upon the said parameter.

27. A method as claimed in claim 26, wherein the said optical fiber is provided with a coating which responds to the said further measurand by stretching or shrinking.

28. A method as claimed in claim 27, wherein the said coating is electro-strictive.

29. A method as claimed in claim 27, wherein the said coating is magneto-strictive.

30. A method as claimed in claim 27, wherein the said coating is sensitive to a selected chemical measurand.

31. A method as claimed in any preceding claim, further comprising the steps of launching optical pulses at a fixed wavelength into the optical fiber and using the returned interference signal to determine high frequency phase changes.

32. A method as claimed in any preceding claim, further comprising the steps of launching optical pulses at a fixed wavelength into an auxiliary optical fiber deployed along the region of interest, reflectors being arrayed along the fiber to form an auxiliary array of sensor elements; and using the returned interference signal from the auxiliary optical fiber to determine high frequency phase changes.

33. A method as claimed in claim 32, wherein the auxiliary fiber has a coating designed to enhance acoustic sensitivity.

34. A method as claimed in any one of claims 31 to 33, wherein the high frequency phase changes are used to correct for dynamic errors in the returned optical interference signals.

35. A method as claimed in any preceding claim, wherein the returned optical interference signal is processed to remove the cross-talk term, the cross-talk term being removed for each of n sensor elements by subtracting the cross-talk phasor

for the nth sensor element from the measured nth sensor element phasor, the removal process beginning with subtraction of the cross-talk phasor for the second sensor element from the measured second sensor element phasor, the cross-talk phasor for the first sensor element in the array being zero.

36. A method according to any preceding claim, wherein the region of interest lies within an oil well.

37. A method according to claim 36, wherein the oil well is a horizontal oil well.

38. A method of measuring a selected physical parameter substantially as hereinbefore described with reference to the accompanying drawings.

39. Apparatus for measuring a selected physical parameter at a location within a region of interest, which apparatus comprises:

an optical fiber for deployment along the region of interest, the optical fiber having reflectors therealong forming an array of sensor elements, the optical path length between the said reflectors being dependent upon the selected parameter;

source means operable to launch optical pulses at a plurality of preselected interrogation wavelengths into the said fiber;

signal detection means operable to detect the returned optical interference signal for each of the preselected wavelengths; and

signal processing means operable to determine from the optical interference signal the absolute optical path length between two reflectors at the said location and to determine from the optical path length so determined the value of the selected parameter at the said location.

40. Apparatus as claimed in claim 39, wherein the said signal processing means is operable to determine the absolute optical path length by carrying out a process in which the derivative of the phase as a function of wavelength is estimated from a subset of the interference signals, using the derivative and an estimated value for the optical path length to estimate the phase relationship between the interference signals, and the phase relationship thus obtained is used to revise the estimated value for the optical path length, the process being repeated for increasing subsets of the remaining wavelengths in sequence, on the basis of the optical path length estimated for the immediately preceding subset in the sequence, thereby to progressively revise the optical path length until it is known to a desired level of accuracy.

41. Apparatus as claimed in claim 40, wherein at least one of the subsets comprises a pair of the interference signals.

42. Apparatus as claimed in any one of claims 39 to 41, wherein the said optical fiber comprises polarization-maintaining fiber, and the apparatus further comprises power launching means operable to launch the optical pulses into the fiber in such a way that the power of the optical pulses is substantially divided between the orthogonally-polarised propagation modes of the fiber, thereby to interrogate each

principal state of polarization of the fiber simultaneously; and the signal processing means being operable to use the returned optical interference signals from both principal states of polarization separately to determine the absolute optical path length for each propagation mode independent of the other mode.

43. Apparatus as claimed in any one of claims 39 to 41, wherein the said optical fiber comprises polarization-maintaining fiber, and the apparatus further comprises a polarization modulator operable to launch the optical pulses into the fiber in such a way that the power of the optical pulses is firstly directed entirely into one of the principal states of polarization of the fiber and then the other, thereby to interrogate the principal states of polarization sequentially; and the signal processing means being operable to use the returned optical interference signals from both principal states of polarization separately to determine the absolute optical path length for each propagation mode independent of the other mode.

44. Apparatus as claimed in any one of claims 39 to 43, wherein the parameter comprises temperature.

45. Apparatus as claimed in claim 44, wherein the region of interest lies within a pipeline, and the signal processing means is further operable to identify any temperature variation within the pipeline from the determined value of the temperature at the said location, where temperature variations are indicative of a change of flow of a fluid in the pipeline.

46. Apparatus as claimed in claim 45, wherein the change of flow arises from a leak of fluid into or out of the pipeline, and the signal processing means is operable to identify a leak at the said location from the identification of a temperature variation at that location.

47. Apparatus as claimed in claim 45, wherein the change of flow arises from a constriction in the pipeline, and the signal processing means is operable to identify a constriction at the said location from the identification of a temperature variation at that location.

48. Apparatus as claimed in any one of claims 39 to 43, wherein the parameter comprises strain.

49. Apparatus as claimed in claim 48, wherein the optical fiber is a high-birefringence fiber, the birefringence of which changes in response to strain applied to the optical fiber.

50. Apparatus as claimed in claim 49, wherein the birefringence of the high birefringence fiber also changes in response to temperature, and the signal processing means is further operable to compensate the returned optical interference signal for effects arising from temperature at the said location.

51. Apparatus as claimed in any one of claims 48 to 50, wherein the region of interest lies on the surface of a component in an oil well, and the signal processing means is

further operable to identify movement of the component from the determined value of strain.

52. Apparatus as claimed in any one of claims 39 to 43, wherein the parameter comprises pressure.

53. Apparatus as claimed in claim 52, wherein the said optical fiber comprises a side-hole fiber.

54. Apparatus as claimed in claim 53, wherein each sensor element of the fiber is located within a sealed elliptical tube filled with a pressure-transmitting fluid.

55. Apparatus as claimed in claim 54, wherein the region of interest lies within a pipeline; the apparatus comprises two or more such optical fibers for deployment at different azimuths around an inner surface of the pipeline; and the signal processing means is operable to determine a density of fluid in the pipeline from the values of pressure determined for each optical fiber.

56. Apparatus as claimed in claim 54, wherein the region of interest lies within a pipeline; the apparatus comprises two or more such optical fibers for deployment at different azimuths around an inner surface of the pipeline, and the signal processing apparatus is operable to determine an orientation of the pipeline and/or the optical fibers from the values of pressure determined for each optical fiber.

57. Apparatus according to any one of claims 39 to 43, wherein the selected parameter depends on a localized event

moving along the region of interest, and the signal processing means is operable to determine the value of the selected parameter over time at more than one said location, and to determine the movement of the localized event from the determined values of the selected parameter.

58. Apparatus according to claim 57, wherein the localized event is a user-induced event.

59. Apparatus according to claim 58, wherein the localized event is a volume of fluid within the region of interest that has a different temperature, pressure, or density from surrounding fluid in the region of interest, the selected parameter being temperature, pressure, or density, respectively.

60. Apparatus as claimed in any one of claims 39 to 59, and further for measuring a second selected physical parameter at the location within the region of interest, wherein said optical path length between the said reflectors is further dependent upon the second selected parameter; and the signal processing means is further operable to determine the value of the second selected physical parameter from the determined absolute optical path length.

61. Apparatus as claimed in any one of claims 39 to 60, further comprising an additional optical fiber provided for deployment through the region of interest, reflectors being arrayed along the additional optical fiber to form an additional array of sensor elements, the said additional

optical fiber being suitable for measurement of a different physical parameter to that of claim 39.

62. Apparatus as claimed in claim 61, wherein the said optical fiber of claim 39 and said additional optical fiber share the same fiber jacket.

63. Apparatus as claimed in claim 61, wherein the optical fiber of claim 39 and the said additional optical fiber are constituted by a single fiber sensitive to both parameters, the fiber having two cores.

64. Apparatus as claimed in any one of claims 61 to 63, operable to use the measured value for the parameter to determine a value for a further measurand dependent upon said parameter.

65. Apparatus as claimed in claim 64, wherein the said optical fiber is provided with a coating which responds to the said further measurand by stretching or shrinking.

66. Apparatus as claimed in claim 65, wherein the said coating is electro-strictive.

67. Apparatus as claimed in claim 65, wherein the said coating is magneto-strictive.

68. Apparatus as claimed in claim 65, wherein the coating is designed to be sensitive to a selected chemical measurand.

69. Apparatus as claimed in any one of claims 39 to 68, wherein the source means are operable to launch light at a fixed wavelength and at a varying wavelength into the fiber, and the signal processing means are operable to use the interference signal from interrogation at the fixed wavelength to determine high frequency phase changes.

70. Apparatus as claimed in claim 69, further comprising an auxiliary optical fiber for deployment through the region of interest, reflectors being arrayed along the fiber to form an auxiliary array of sensor elements, the source means being operable to launch the fixed wavelength signal into the auxiliary fiber.

71. Apparatus as claimed in claim 70, where the auxiliary fiber has a coating designed to enhance acoustic sensitivity.

72. Apparatus as claimed in any one of claims 69 to 71, wherein the signal processing means are further operable to use the high frequency phase changes to correct for dynamic errors in the returned optical interference signals.

73. Apparatus as claimed in any of claims 39 to 72, wherein the signal processing means is further operable to process the returned optical interference signal to remove the cross-talk term, the cross-talk term being removed for each of the n sensor elements by subtracting the cross-talk phasor for the nth sensor element from the measured nth sensor element phasor, the removal process beginning with subtraction of the cross-talk phasor for the second sensor element from the

measured second sensor element phasor, the cross-talk phasor for the first sensor element in the array being zero.

74. Apparatus according to any one of claims 39 to 73, wherein the region of interest lies within an oil well.

75. Apparatus according to claim 74, wherein the oil well is a horizontal oil well.

76. Apparatus for measuring a selected physical parameter substantially as hereinbefore described with reference to the accompanying drawings.

77. A method of measuring a parameter in an optical fiber interferometric array, comprising:

launching optical pulses into the array,

creating an interference signal within sensor elements in the array,

detecting the phase of the interference signals, wherein the returned optical interference signal is processed to remove the cross-talk term, the cross-talk term being removed for each of n sensor elements by subtracting the cross-talk phasor for the nth sensor element from the measured nth sensor element phasor, the removal process beginning with subtraction of the cross-talk phasor for the second sensor element from the measured second sensor element phasor, the cross-talk phasor for the first sensor element in the array being zero.